Gamma ray multiplicity in the quasi-fission of Cu + Au at 443 MeV

M. Berlanger, M.A. Deleplanque, C. Gerschel, F. Hanappe, M. Leblanc, J.F. Mayault, C. Ngo, D. Paya, N. Perrin, J. Péter, et al.

To cite this version:

M. Berlanger, M.A. Deleplanque, C. Gerschel, F. Hanappe, M. Leblanc, et al.. Gamma ray multiplicity in the quasi-fission of Cu + Au at 443 MeV. Journal de Physique Lettres, 1976, 37 (12), pp.323-325. 10.1051/jphyslet:019760037012032300 . jpa-00231303

HAL Id: jpa-00231303
https://hal.science/jpa-00231303

Submitted on 1 Jan 1976

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Classification
Physics Abstracts
4.375

GAMMA RAY MULTIPLICITY IN THE QUASI-FISSION OF Cu + Au AT 443 MeV

M. BERLANGER (*), M. A. DELEPLANQUE, C. GERSCHEL, F. HANAPPE (*), M. LEBLANC, J. F. MAYAULT, C. NGÔ, D. PAYA (**), N. PERRIN, J. PÉTER, B. TAMAIN and L. VALENTIN

Institut de Physique Nucléaire, BP n° 1, 91406 Orsay, France

(*Reçu le 2 septembre 1976, révisé le 16 septembre 1976, accepté le 23 septembre 1976*)

Résumé. — Nous avons mesuré la multiplicité γ associée au processus de quasi-fission du système Cu + Au à 443 MeV. La valeur obtenue croît avec le degré d'inélasticité. Elle a un maximum de 25 à 35° (correspondant à des ondes partielles initiales d'environ 150 $\hbar$) et de 22 à 49° (près de l'angle d'effleurement). En tenant compte du moment angulaire emporté par les particules émises et de la déformation des fragments au point de scission, l'hypothèse du *collage* est en accord avec ces valeurs. Nous discutons également la possibilité d'un moment angulaire additionnel dû au processus de quasi-fission lui-même. Nous donnons enfin une mesure de la multiplicité γ associée à la fission séquentielle.

Abstract. — We have measured the γ-ray multiplicity associated with the quasi-fission of the system ^{63}Cu + ^{197}Au at 443 MeV lab. energy. Its value increases with the degree of inelasticity. The maximum values are 25 at 35° (corresponding to initial l-waves of about 150 $\hbar$) and 22 at 49° (close to the grazing angle). Taking into account the angular momentum carried away by emitted particles and the deformation of the fragments at the scission point, these values agree with the sticking hypothesis. The possibility of additional angular momentum imparted to the fragments by the quasi-fission process itself is discussed. The γ-multiplicity associated with sequential fission has also been measured.

1. **Introduction.** — The qualitative features of deep inelastic collisions have been often interpreted [1] on the basis of a three-step mechanism : i) the relative motion of the two incoming nuclei is first slowed down by the nuclear viscosity, ii) the composite system rotates, iii) the two partners separate after an exchange of nucleons; the rotation angle and the number of exchanged nucleons depend on the contact time. During the second step, the two partners can either stick together (sticking hypothesis) or roll one around the other (rolling hypothesis) depending on the relative importance of the tangential and radial friction. One way to obtain information about tangential friction is to measure the angular momentum $(l_1 + l_2)$ carried away by the two outgoing products. The sticking hypothesis corresponds to the greatest angular momentum transfer to the fragments [9] :

$$\Delta l = (l_1 + l_2) = l_i \frac{J_1 + J_2}{J_1 + J_2 + J_b} \qquad (1)$$

where l_i is the incoming angular momentum, J_1 and J_2 are the moments of inertia of the outgoing nuclei and the denominator is the total moment of inertia relative to the rotation axis of the system.

We measured the γ-ray multiplicity in the deep inelastic collisions for the system Cu + Au at 443 MeV (335 MeV c.m.). This type of experiment has already been performed for three systems (O + Ni at 96 MeV [2], N + Nb at 120 MeV [3], Ar + Ni at 280 MeV [4]) but only the N + Nb results seem to agree with the sticking hypothesis. In our case ($Z_1 Z_2 = 2\,291$, 1.4 times the Coulomb barrier), i) l_i values are larger (up to 175 $\hbar$), ii) completely relaxed events can be easily identified, iii) charged particle emission is expected to be negligible.

The γ-ray multiplicity M_γ is determined by measuring during the same period, the number N_S of simple events in the fragment detector and the number N_C of fragment-γ-ray coincidences. In the case of an isotropic γ-ray angular distribution, one gets M_γ from :

$$N_C = N_S(1 - (1 - \Omega_\gamma)^{M_\gamma}) \simeq N_S\, \Omega_\gamma\, M_\gamma \qquad (2)$$

where Ω_γ is the total efficiency of the γ detector including solid angle.

(*) Physique Nucléaire, Université Libre de Bruxelles, Belgique.
(**) CEN Saclay, DPhN/MF, France.

Article published online by EDP Sciences and available at http://dx.doi.org/10.1051/jphyslet:019760037012032300

2. **Experiment.** — We identified the deep inelastic products in two 600 mm^2 surface barrier detectors at 35° and 49° to the beam, 10 cm away from the 500 g/cm^2 Au target. The gamma-rays emitted by both products were detected in two 7.5 cm × 7.5 cm NaI detectors located in the reaction plane at 90° and 158° to the beam, 60 cm away from the target. A third 7.5 cm × 7.5 cm NaI detector also 60 cm from the target was used to detect the γ-rays in the direction perpendicular to the reaction plane. All crystals were screened by 1 mm of lead and 3 mm of copper. The thresholds were set at 300 keV. Figures 1*a* and 2*a* show direct kinetic energy spectra in the two detectors. For each coincidence between fragment and γ-ray, we have recorded the fragment energy, the γ-ray energy, and the time of flight difference between the γ-ray and the fragment. This last quantity was used to discriminate γ-rays against neutrons and to be sure of the origin of γ-rays.

Quasi-fission events (i.e. completely energy relaxed events) were identified only by their kinetic energy as was suggested in ref. [6]. The 35° angle was chosen because it corresponds to the maximum of the angular distribution [6] of the light quasi-fission fragments, and because the quasi-fission fragments (central peak in figure 2*a*) are clearly separated from other products (elastic + quasi-elastic Cu nuclei : right peak in figure 2*a*). The other angle (49°) close to the grazing angle (52°) was chosen because of the continuous transition between the elastic, quasi-elastic and quasi-fission components (see Fig. 1*a*). This allows us to study the connection between the γ-ray multiplicity and the degree of relaxation.

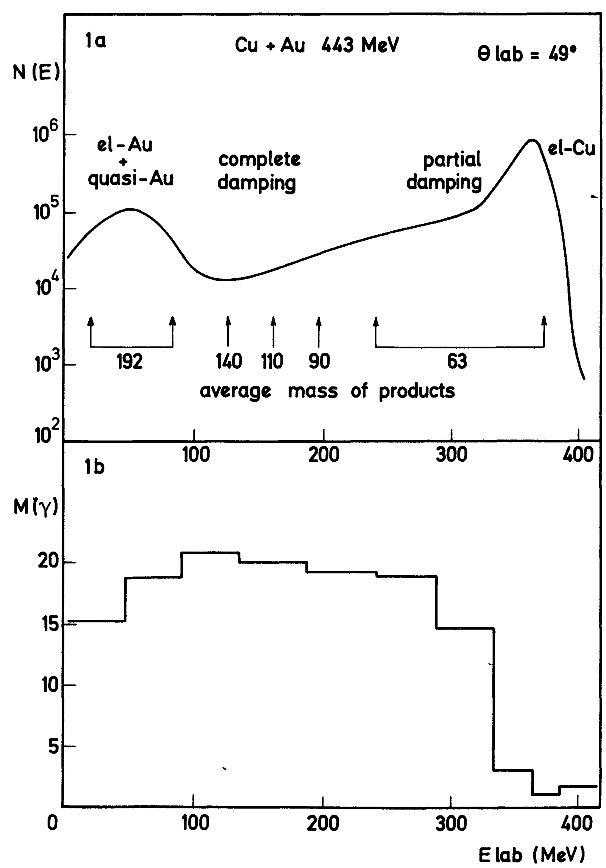

FIG. 1*a*. — Energy spectrum (log scale) of the products detected by the 49° surface barrier detector. The arrows indicate the average mass associated with the kinetic energy scale (the correlation mass-energy has been obtained from ref. [5]).

FIG. 1*b*. — Corresponding average γ-ray multiplicity. The relative uncertainties are < 2 %.

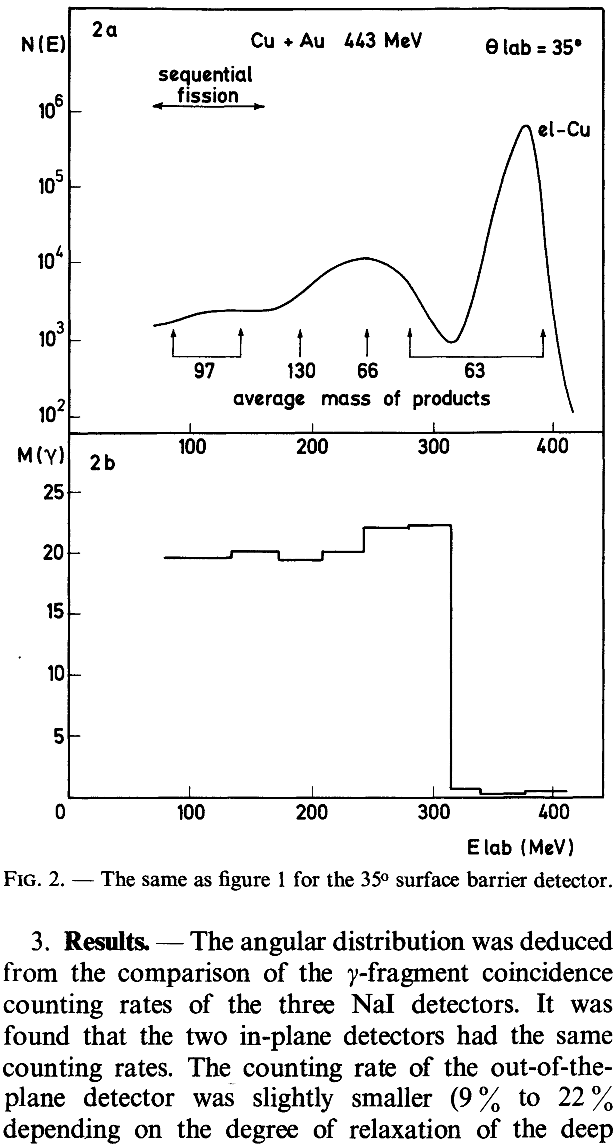

FIG. 2. — The same as figure 1 for the 35° surface barrier detector.

3. **Results.** — The angular distribution was deduced from the comparison of the γ-fragment coincidence counting rates of the three NaI detectors. It was found that the two in-plane detectors had the same counting rates. The counting rate of the out-of-the-plane detector was slightly smaller (9 % to 22 % depending on the degree of relaxation of the deep inelastic products). We have not taken into account this slight anisotropy in the determination of the γ-ray multiplicity. The average total efficiency of the NaI detectors ((3.4 ± 0.5) 10^{-4}) was obtained without unfolding the spectra. The γ-ray multiplicity results are shown in figures 1*b* and 2*b*. It appears that, as expected, the γ-ray multiplicity is much higher for quasi-fission events than for elastic plus quasi-elastic events. In figure 1*b* the increase of the multiplicity with decreasing kinetic energy of the fragment clearly indicates the correlation between the angular momentum transfer and the degree of relaxation. The left peak in figure 1*a* corresponds to an admixture of elastic plus quasi-elastic plus quasi-fission gold nuclei ;

the corresponding multiplicity is then intermediate between the quasi-fission and the elastic plus quasi-elastic multiplicity. In figure 2*b*, the slight decrease of the multiplicity for decreasing quasi-fission energy (central peak) is due to the mass transfer observed in that quasi-fission process [5] (see the arrows in figure 2*a*) : for more symmetric outgoing products, the angular momentum transfer is expected to decrease (see relation (1)).

4. **Discussion.** — The γ-ray spectra exhibit the usual shape observed in the de-excitation of compound nuclei [10]. The number of statistical γ-rays is about 10 % of the total. Then, assuming the statistical γ-rays transitions to be mostly E_1 and yrast transitions mostly E_2 [10], the mean angular momentum carried away by one γ-ray is 1.9 $\hbar$. For completely relaxed events detected at 35° and 49° the average angular momentum Δl carried away by the photons are then $(47 \pm 6)\,\hbar$ and $(41 \pm 6)\,\hbar$ respectively.

On these values one can make the following comments. The excitation energy is about 135 MeV for most of the outgoing fragments (those with low mass transfer) [5]. About 15 MeV are removed by the γ-rays. It seems, according to recent results for a neighbouring system, that the probability of charged particle emission is low. We then assumed that the remaining 120 MeV are removed by approximately 12 evaporated neutrons which corresponds to about 12 $\hbar$. The emission of preequilibrium neutrons, if any, will not change significantly this result. The total angular momentum carried away by the quasi-fission products is then about 55 $\hbar$. The possible existence of some isomeric states [8] in the gold region may add up a few $\hbar$.

We can now compare the obtained angular momentum to a calculation performed in the sticking hypothesis framework. For two spherical tangential fragments, at the scission point, the relation (1) indicates that $\Delta l = 0.4\ l_i$. A more realistic calculation can take into account the deformation of the quasi-fission fragments at the scission point. To calculate this deformation, we used the value of the total kinetic energy of the quasi-fission products [6] (200 MeV when there is no mass transfer) and we assumed that : i) the two nascent fragments are spheroidal with the same eccentricity; ii) at the scission point, their relative kinetic energy is zero; iii) their final kinetic energy is due to Coulomb + rotational energy. The ratio of major to minor axis at the scission point was found equal to 1.3 ($\beta = 0.31$) leading to $\Delta l = 0.33\ l_i$. The calculation of l_i has been performed by using : i) the quasi-fission angular distribution published in ref. [6]; ii) the hypothesis that the quasi-fission events detected near the grazing angle correspond to the highest l-waves involved in quasi-fission and that lower angles correspond to decreasing l_1 values [5]. l_i is thus ~ 170 at 49° and ~ 150 at 35° leading to a Δl value of about 56 at 49° and 50 at 35°, very close to the experimental values.

Let us now discuss our results relative to the γ-ray angular distribution. We already noticed that it was nearly isotropic [10] and that the γ transitions are mainly E_2. Therefore, we think that the absence of a strong anisotropy is due to the fact that the spins are not fully aligned perpendicular to the plane of the reaction. An explanation could be found by analogy with the fission process. In spontaneous and neutron-induced fission, where the initial spin is very small, it has been established that the total spin of the fragments is about 15 $\hbar$ [11] due to a bending mode. One can think that a similar effect also occurs in the last step of the quasi-fission process; the direction of this additional spin is not aligned with the incoming angular momentum. This assumption is also supported by the fact that the angular anisotropy of the γ-rays is found lower for a greater contact time, i.e. for more relaxed events or for greater mass transfer.

We have also observed a low energy bump in the 35° detector (Fig. 2*a*). These events are due to a quasi-fission reaction followed by a fission of the heavy partner as suggested in ref. [5]. They will be discussed later.

References

[1] MORETTO, L. G., SVENTEK, J. S., Internal Report Berkeley, LBL 5006 (1976).
NGÔ, C., PÉTER, J., TAMAIN, B., BERLANGER, M., HANAPPE, F., Internal Report Orsay IPNO.RC.75.09 (1975), *Nucl. Phys.* in press.

[2] ALBRECHT, R., DUNNWEBER, W., GRAW, G., HO, H., STEADMAN, S. G., WURM, J. P., *Phys. Rev. Lett.* **34** (1975) 1400.

[3] ISHIHARA, M., NUMAO, T., FUKUDA, T., TANAKA, K., INAMURA, T., preprint 1976.

[4] BOCK, R., FISCHER, B., GOBBI, A., HILDENBRAND, K., KOHL, W., LYNEN, U., RODE, I., STELZER, H., BACK, B., ALBRECHT, R., AUGER, G., GALIN, J., LAGRANGE, J. M., *J. Physique Colloq.* **37** (1976) C5.

[5] PÉTER, J., NGÔ, C., PLASIL, F., TAMAIN, B., BERLANGER, M. and HANAPPE, F., submitted to *Nucl. Phys.*

[6] TAMAIN, B., PLASIL, F., NGÔ, C., PÉTER, J., BERLANGER, M. and HANAPPE, F., *Phys. Rev. Lett.* **36** (1976) 18.

[7] BENSON, D., CATCHEN, G., KOWALSKI, L., LOGAN, D., LU, N., MILLER, J., SINGH, U. N., ALEXANDER, J., DEBIAK, T., GUIDRY, M., *J. Physique Colloq.* **37** (1976) C5.

[8] KRATZ, J. V., BRÜCHLE, W., DREYER, I., FRANZ, G., WIRTH, G., SCHADEL, M., WEISS, M., *J. Physique Colloq.* **37** (1976) C5.

[9] BONDORF, J. P., Lecture given in International School of Physics, *Enrico Fermi*, Villa Monastero, Varenna, 1974.

[10] SIMON, R. S., BANASCHIK, M. V., COLOMBANI, P., SOROKA, D. P., STEPHENS, F. S., DIAMOND, R. M., *Phys. Rev. Lett.* **36** (1976) 359.

[11] HYDE, E. K., The Nuclear Properties of the heavy elements III, Prentice Hall, 1964.